ACTIVE FAULTING IN NORTHERN TURKEY[1]

Clarence R. Allen

Seismological Laboratory, California Institute of Technology

The North Anatolian fault zone of Turkey has become widely publicized in recent years because of the remarkable series of earthquakes that began along it in 1939 -- most of which have been associated with dextral surface displacements that have successively delineated the fault trace from east to west (Ketin and Roesli, 1953; Ambraseys and Zátopek, 1968). It is not so generally recognized that even prior to 1939 the fault zone could easily have been recognized on the basis of abundant and throughgoing features of Quaternary displacements, and that the North Anatolian fault is almost completely analogous to the better-known active transcurrent faults of the circum-Pacific region, such as the San Andreas fault of California and the Alpine fault of New Zealand.

Convincing evidence of throughgoing Quaternary transcurrent faulting can be traced continuously for more than 900 km along the North Anatolian fault in a broad arc from west of Abant (Bolu Prov.) to east of Karlıova (Bingöl Prov.), except for two areas of en-echelon offset near Niksar (Tokat Prov.) and Erzincan. Distinctive "rift topography" and abundant features of Quaternary faulting such as scarps in alluvium, offset streams, side-hill ridges, springs, and sag ponds mark the fault throughout its extent; and the very linearity of the fault over literally hundreds of kilometers is completely analogous to that of other regional transcurrent faults (Allen, 1965).

---

[1] Contribution No. 1577, Division of Geological Sciences, California Institute of Technology.

It should be particularly emphasized that, except for the two areas of en-echelon offset, Quaternary displacements delineate a continuous fault over the entire 900-km interval -- not the fragmented and discontinuous zone that is suggested by most existing geologic maps of the region.

As is typical of other active fault systems in mountainous areas, physiographic features of Quaternary displacement along the North Anatolian fault are much better preserved in the passes between river drainage systems than in the fault-controlled valleys that delineate most of the fault trace. This is due not only to the more active erosional and depositional processes that tend to obliterate scarps in the river valleys, but also because the lowland areas have been subject to cultural modification by farming for many hundreds of years. Despite the absence of obvious evidence of faulting in some of the most heavily cultivated lowland areas, such as in the valley south of Bolu, nearly every fault-controlled drainage divide between major rivers is marked by a conspicuous sag pond at the very crest of the pass. Among the more notable of these are: Abant Göl (Lake), 32 km southwest of Bolu; Umman Göl, on the high divide 19 km northwest of Ilgaz (Çankırı Prov.); Gölbel, at the major pass 18 km northeast of Osmancık (Çorum Prov.); and at the main divide east of the Erzincan Valley, about 65 km southeast of Erzincan.

Inasmuch as most of the trace of the North Anatolian fault is delineated by major river valleys that have been eroded within the crushed zone, drainages that cross the fault at right-angles are relatively rare, and lateral stream offsets are thus not as common as along some other major transcurrent faults. Nevertheless, in those mountainous areas where the fault cuts across numerous closely spaced tributary streams, consistent dextral stream offsets are conspicuous and convincing. From west to east, probably the most diagrammatic such areas are: (1) 12 km north of Ilgaz (Çankırı Prov.), between the villages of Ekşik and Çomar, where many streams of different sizes are offset by varying amounts -- the large streams more than the small; (2) 40 km east of Kargı (Kastamonu Prov.), where more than 15 tributary canyons of the Soruk Deresi near the village of Tahtaköprü are consistently offset; (3) near Destek (Tokat Prov.), where more than 20 streams tributary to the Destek Çayı are clearly offset; (4) along the mountain front 10 km northwest of Erzincan, where several large canyons are offset as much as 1/2 km; and (5) along the easternmost segment of the fault 10 km northwest of Karlıova (Bingöl Prov.), where numerous north-flowing tributaries of the Elmalı Deresi are uniformly offset near the village of Cerme. In nearly all of these examples, the offsets are in the direction of the "uphill" regional topographic gradient, thus precluding apparent offset by differential erosion (Allen, 1962). Some of the largest rivers are seemingly offset as much as 50 km in a dextral sense, such as the Fırat Nehrı near Erzincan, the Kızılırmak near Kargı, and the Sağanlı Çayı east of Gerede; whether or not these suggestive offsets are in fact tectonic in origin, however, must remain doubtful for the moment.

Many of the areas noted above are not easily visited, but three easily accessible and widely separated areas where the fault is diagrammatically exposed are as follows:

(1) Rift topography is particularly well developed east and west of the city of Gerede (Bolu Prov.), in full view of the main İstanbul-Ankara

highway. The distinct trough along the fault zone lies athwart the topographic gradient, so that numerous stream courses within the trough demonstrate tectonic offset, capture, and damming (Erinç, Bilgin, and Bener, 1961; Wallace, 1968). A conspicuous large sag pond lies 2 km west of the city, and several fault-dammed ponds occur 20 km farther east near the village of Kapaklı. The scarp of the 1944 earthquake (M = 7.6) is clear throughout much of this segment and is almost invariably located along the line of earlier scarps; the trace passed directly through Gerede, and several walls can still be seen to be laterally offset.

(2) North of Lâdik (Samsun Prov.), the North Anatolian fault for many kilometers is particularly reminiscent of the San Andreas fault in its general physiographic expression. Numerous elongate closed depressions mark the fault trace, and the road follows a distinct sidehill ridge for 2 kms through the village of Arslantas, where the fault is crossing from one drainage system to another. About one meter of dextral displacement was reported here at the time of the 1943 earthquake (M = 7.6). The fault crosses the main highway and railroad to Samsun 13 km northwest of Arslantas, and although several good sag ponds occur on each side of the railroad, the fault trace is not obvious from the nearby highway.

(3) The valley east of Suşehri (Sivas Prov.) is a major fault-controlled feature. Especially near the village of Küçükgüzel, 12 km east of Suşehri, elongate sag ponds and fresh scarps cut the flat valley floor, in part resulting from the disastrous 1939 earthquake (M = 8.0), which took many lives in this area. Numerous scarps, springs, and sag

ponds continue farther southeast along the fault. Particularly near Çobanlı, 45 km southeast, the main river through the village is distinctly offset at the fault, the adjacent lakes are clearly fault-dammed, and the nearby village of Tümeçker lies at the end of a diagrammatic fault trough.

One of the most surprising features of the North Anatolian fault is the very abrupt eastward termination of Quaternary displacements 10 km east of Karlıova (Bingöl Prov.), near the village of Kargapazar. Northwest from this point features of active faulting are as fresh and impressive as anywhere along the fault throughout northern Turkey, yet within an interval of less than 5 km, virtually all throughgoing features of Quaternary displacement die out. Still farther east, the dominant tectonic style seems to be that of block faulting along more northwesterly trends. It is in this area that the 1966 earthquake (M = 7) occurred near Varto (Muş Prov.), which is nearly in line with the North Anatolian fault. Some of the minor faulting during this earthquake was indeed parallel to the North Anatolian system and dextral in sense (Wallace, 1968; Ambraseys and Zátopek, 1968), but the surface breaks obviously lacked the continuity of the earlier breaks farther west. Despite the occurrence of the 1966 Varto shock, the author feels that the principal active segment of the North Anatolian fault terminates on the east near Karlıova, and that the tectonic style distinctly changes east of that point.

A possible mechanical explanation for the abrupt ending of the northwest-trending North Anatolian fault near Karlıova is that a southwest-trending conjugate fault terminates at nearly the same point -- forming an eastward-pointed wedge. This fault, part of which is described by Altınlı, Pamir, and Erontöz (1963), continues southwestward from Karlıova for more than 70 km, marked by fresh scarps, closed depressions, and numerous springs for almost the entire distance to Bingöl. Still farther southwest, only scattered segments show Quaternary activity, and the overall continuity of the fault zone has not been documented. Several sag ponds, linear rift valleys, and scarps in alluvium mark the 50-km segment between Palu and Hazar Gölü (Elazig Prov.), and Hazar Gölü itself must be regarded as a giant sag pond; distinct Quaternary scarps extend both northeast and southwest from its shores, the latter break extending at least as far southwest as the Fırat River. The trend of this major fault system is such that, if projected still farther southwest into areas not studied by the author, it would line up nicely with the Dead Sea fault system extending north from Israel. The Dead Sea system is clearly sinistral in its sense of displacement (Freund, 1965), and whereas only suggestive evidence of sinistral displacement has as yet been identified in Turkey, it seems likely that this sense of displacement characterizes the entire northeast-trending system. This might explain the abrupt termination of Quaternary faulting at the point where the two systems meet near Karlıova -- essentially cancelling each other out -- and it is significant that the angle at which they abut is almost identical to that between the dextral San Andreas fault and the sinistral Garlock fault in California.

At the western end of the fault, its mode of termination is not as clear as on the east. West of Abant Göl (Bolu Prov.), Quaternary displacements are difficult to discern because of heavy forest vegetation and massive landsliding in the mountainous terrain, but it appears that the system frays-out westward into a series of diverging breaks. No single principal fracture can be followed continuously to the Aegean Sea, although many of the topographic features in the coastal region are clearly fault-controlled and lie parallel to the North Anatolian fault trend; several elongate lakes and closed depressions in the Isnik-Gemlick area (Bursa Prov.) are good examples, as are many of the topographic features east and west of İzmit (Kocaeli Prov.).

Pavoni (1961) has suggested that the total lateral displacement on the North Anatolian fault may be several hundred kilometers. The present author has little to add to this argument except to emphasize that the length of the fault, its linearity through regions of diverse rock types, and the great width of the crushed zone are comparable to those of other regional faults along which large displacements have been well documented. As is typical of other such faults, good exposures of rocks within the North Anatolian fault are rare; probably the best exposure observed by the author was in the canyon of the Kelkit River, 20 km west of Reşadiye (Tokat Prov.), where completely crushed and pulverized slices of rock have been exposed over a width of several hundred meters. The most recent displacements within the zone, as indicated by nearby fault scarps, have generally been limited to a single strand, despite the great width of the zone that presumably represents a long and complex history of fracturing.

Certainly the most remarkable historic phenomenon associated with the North Anatolian fault has been the generally westward progression of dextral surface displacements along the fault trace starting with the great Erzincan earthquake of 1939-- a successcion of events in time and space that has been reported nowhere else in the world. This unique behavior was first pointed out by Ketin (1948), and most of the data including that of the more recent events has been summarized by Ambraseys and Zátopek (1968). It should be emphasized, however, that the remarkable series of earthquakes during the past 30 years does not appear to be typical of events during the last one or two hundred years; in talking to many farmers living along the fault trace, the author found none who could recall having observed or having heard stories of pre-1939 ground displacements -- despite the fact that details of the 1939 and subsequent events are indelibly fixed in their memories. This suggests that major earthquake sequences associated with surface faulting, such as characterizes the present epoch, are relatively infrequent events, and that following the present spasm of activity the fault may again be relatively quiescent for a period of perhaps several hundred years.

The author has argued that those segments of the San Andreas fault in California where Quaternary displacements have been the most continuous and throughgoing are the segments most likely to experience great earthquakes at very infrequent intervals, whereas those segments characterized by branching and complex surface fault patterns have very frequent earthquakes but of much smaller average magnitude (Allen, 1968). The same seismotectonic generalization may apply to Turkey: easternmost and westernmost Turkey, which are characterized by complex and discontinuous fault patterns, seem to have very frequent earthquakes of moderate magnitudes (Ergin, Güçlü and Uz, 1967), whereas truly great earthquakes -- albeit infrequent -- may be limited to those parts of Turkey dominated by a long, throughgoing fault system such as the North Anatolian fault zone between Abant and Karlıova.

ACKNOWLEDGMENTS

The author's work in Turkey was made possible by the generous cooperation of the Minerals Research and Exploration Institute (Maden Tetkik ve Arama Enstitüsü -- M. T. A.), Dr. S. Alpan, General Director. The field work would have been impossible without the kind help of İ. Ketin of Istanbul Technical University and Özcan Aksoy of the M. T. A. In addition to the logistical help obtained through Istanbul Technical University and the M. T. A. , the work was supported by the G. K. Gilbert Award in Seismic Geology adminstered through the Carnegie Institution of Washington.

REFERENCES

Allen, C. R. , 1962, Circum-Pacific faulting in the Philippines-Taiwan region: Jour. Geophys. Research, v. 67, p. 4795-4812.

Allen, C. R. , 1965, Transcurrent faults in continental areas: Royal. Soc. (London) Philos. Trans. A. , v. 258, p. 82-89.

Allen, C. R. , 1967, The tectonic environments of seismically active and inactive areas along the San Andreas fault system: Stanford Univ. Pub. Geol. Sci. , v. 11, p. 70-82.

Altinli, I. , Pamir, H. , and Erentöz, C. , 1963, 1:500,000 Ölcekli, Türkiye Jeoloji Haritası, Erzurum: Maden Tetkik ve Arama Enstitusü, Ankara, 131 p.

Ambraseys, N. N. , and Zátopek, A. , 1968, The Varto Üstükran (Anatolia) earthquake of 19 August 1966 -- summary of a field report: Seismol. Soc. America Bull. , v. 58, p. 47-102.

Ergin, K. Güçlü, U., and Uz, Z., 1967, Türkiye ve civarının deprem Kataloğu: İstanbul Teknik Üniversitesi, Maden Fakültesi, 169 p.

Erinç, S., Bilgin, T., and Bener, M., 1961, Gerede Civarinda Akarsu Şebekesi: İstanbul Üniversitesi, Coğrafya Enstitüsü Dergisi, v. 7, p. 90-99.

Freund, R., 1965, A model of the structural development of Israel and adjacent areas since Upper Cretaceous times: Geol. Mag., v. 102, p. 189-205.

Ketin, İ., 1948, Über die tektonisch-mechanischen Folgerungen aus den grossen anatolischen Erdbeben des letzten Dezenniums: Geol. Rundschau, v. 36, p. 77-83.

Ketin, İ., and Roesli, F., 1953, Makroseismische Untersuchungen über das nordwestanatolische Beben vom 18 März 1953: Eclogae Geol. Helvetiae, v. 46, p. 187-208.

Pavoni, N., 1961, Die nordanatolische Horizontalverschiebung: Geol. Rundschau, v. 51, p. 122-139.

Wallace, R. E., 1968, Earthquake of August 19 1966, Varto area, eastern Turkey: Seismol. Soc. America Bull., v. 58, p. 11-45.